The Determinants of Fishing Vessel Accident Severity

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Abstract

The study examines the determinants of fishing vessel accident severity in the Northeastern United States using vessel accident data from the U.S. Coast Guard for 2001-2008. Vessel damage and crew injury severity equations were estimated separately utilizing the ordered probit model. The results suggest that fishing vessel accident severity is significantly affected by several types of accidents. Vessel damage severity is positively associated with loss of stability, sinking, daytime wind speed, vessel age, and distance to shore. Vessel damage severity is negatively associated with vessel size and daytime sea level pressure. Crew injury severity is also positively related to the loss of vessel stability and sinking.

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1. Introduction

Commercial fishing is a dangerous occupation, and accidents are bound to happen given the operational environment within which fishing is conducted. In the United States, during 1992-2008, an annual average of 58 reported deaths occurred (128 deaths per 100,000 workers) in the fishing industry, compared with an average of 5,894 deaths (four per 100,000 workers) among all U.S. workers. Among the 504 U.S. commercial fishing deaths during 2000-2009, the majority occurred after a vessel accident (52%) or a fall overboard (31%). A quarter of the deaths occurred in the Northeast region. The fisheries with the highest fatality rates include Northeast multispecies groundfish fishery (600 per 100,000 full-time equivalent employees) and Atlantic scallop (425 per 100,000 full-time equivalent employees) (Lincoln and Lucas 2010).

The risk associated with commercial fishing may be defined as the product of the probability of an adverse outcome (event probability) and the severity of that outcome (Windle *et al*. 2008). The adverse outcome typically involves vessel damage and crew injury. The severity of vessel damage may vary from no damage to the loss of the vessel. The severity of crew injury may also vary from no injury to death. This study investigates the determinants of fishing vessel accident severity. Specifically, we examine fishing vessel accidents in the waters off the coast of Northeastern United States using the U.S. Coast Guard data from 2001 to 2008. Is the accident severity of a fishing vessel more likely to be greater for a certain type of vessel accident, vessel characteristic, weather condition, and season? The results of the investigation will be useful for policymakers that regulate the safety of fishing vessels, insurance companies that insure fishing vessels, and fisheries managers.

The paper extends our earlier studies of fishing vessel accidents in U.S. waters from 1981 to 2001. Jin *et al*. (2001) found that the probability of a total loss of the vessel was the greatest for a capsizing, followed by a sinking accident. Fire/explosions and capsizings were expected to incur the greatest number of crew fatalities: 3.5 and 3.8 for every 100 such accidents. For every 100 collisions, 2.1 nonfatal crew injuries were expected. The probability of a total loss and the expected number of crew fatalities varied inversely with the price of fish catches.

In another study, Jin and Thunberg (2005) investigated fishing vessel accident probability and vessel trip probability in North Atlantic U.S. EEZ fisheries using logit regression and daily data from 1981 to 2000. The study showed that fishing vessel accident probability declined over the study period. Higher wind speeds were associated with greater accident probability. Medium size vessels had the highest accident probability before 1994. Within the study region, accident probability was lower in southern New England and Mid-Atlantic waters than on Georges Bank and in the Gulf of Maine. Accidents were more likely to occur closer to shore than offshore. Accident probability was lower in spring and fall. Changes in fishery management in 1994 did not lead to a general increase in either accident or vessel trip probability. Although higher economic payoff (i.e., revenue of landings) induced more vessels to go fishing, this was not associated with an increase in accidents.

A comprehensive, multi-national review of fishing vessel safety studies can be found in Windle *et al*. (2008). Results of their study highlight the need for an improvement in assessment and for access to accurate and standardized statistics regarding fishing-related injuries and illnesses.

The paper is structured as follows. In Section 2, a model of the fishing vessel accident severity is presented. Data are discussed in Section 3. Sections 4 and 5 describe estimation procedures and results, respectively. Estimated marginal effects are presented in Section 6. Conclusions are set forth in Section 7.

2. The model

According to vessel accident literature (Talley *et al*. 2006 and 2008), the fishing vessel accident damage severity (D) is expected to vary with the type of vessel accident (**a**), vessel characteristics (**c**), type of vessel propulsion (**p**), type of vessel hull construction (**h**), weather condition (**w**), spatial location (**s**), and time of vessel accident (**t**), i.e.,

$$D = f(\mathbf{a}, \mathbf{c}, \mathbf{p}, \mathbf{h}, \mathbf{w}, \mathbf{s}, \mathbf{t}) \tag{1}$$

Each vector on the right hand side of equation (1) consists of a number of measurement variables. The type of accident (**a**) includes many traditional variables found in Coast Guard statistics (i.e., allision, capsize, collision, explosion, fire, flooding, grounding, material failure, and sinking),[1] several new variables describing post-ship-accident activities (i.e., vessel abandonment, vessel set adrift, loss of electrical power, and losses of vessel stability and maneuverability), and other new variables (i.e., vessel caused environmental damage and vessel requested emergency response). The vessel damage severity is expected to be greater if the vessel sank resulting from an accident. Otherwise, the *a priori* relationship between type of accident and D is indeterminate.

Vessel characteristics (**c**) include vessel size (gross ton) and vessel age. The *a priori* sign of the relationship between accident vessel damage severity and vessel size is negative, as larger vessels are expected to be more seaworthy (e.g., less susceptible to adverse weather). The *a priori* sign of the relationship between damage severity and vessel age is positive, since vessel structural failure is expected to increase with age.

[1] An allision accident occurs when a vessel strikes a stationary object (not another vessel) on the water surface. A collision accident occurs when a vessel strikes or was struck by another vessel on the water surface. A grounding accident occurs when the vessel is in contact with the sea bottom or a bottom obstacle. A material-failure accident typically involves equipment failure on board the vessel.

Propulsion for a fishing vessel (**p**) includes diesel and gasoline engines. It is unclear, however, which of these propulsion sources are expected to result in greater vessel damage. A vessel's hull (**h**) may be constructed with aluminum, fiberglass, steel, or wood. Since steel is the strongest of these materials, it is expected that a vessel constructed with steel will incur less damage, all else held constant.

Weather condition (**w**) is represented by the daily maximum wind speed (m/s) and daily maximum sea level pressure (hPa). The spatial variable (**s**) measures the distance to shore (km). Time of vessel accident (**t**) includes time of day (nighttime versus daytime) and time of year (seasons). These variables capture the effects of changes in visibility as well as general weather conditions. Adverse weather and visibility are expected to increase the risk of a vessel accident, in turn, the vessel's damage severity. Replacing the vectors in equation (1) with the above described measurement variables (**x**), one obtains the fishing vessel accident damage severity reduced-form equation:

$$D = F(\mathbf{x}) \tag{2}$$

Crew injury severity (J) in a fishing vessel accident is expressed as a function of vessel damage severity (D) and other factors in equation (1), such as accident type, i.e.,

$$J = g(D, \mathbf{a}, \mathbf{c}, \mathbf{p}, \mathbf{h}, \mathbf{w}, \mathbf{s}, \mathbf{t}) \tag{3}$$

Vessel damage severity should have a non-negative effect on the crew injury severity given that a damaged vessel does not necessarily result in injured crew members. Also, more injuries are expected to occur under bad weather conditions. The a priori relationships between J and vessel characteristics and other variables are unclear. Replacing the vectors in equation (3) by the variables used to measure them and rewriting, one obtains the crew injury severity reduced-form equation:

$$J = G(\mathbf{x}) \tag{4}$$

In the study, we develop two sets of regression models for accident severity, one for vessel damage (*D*) and the other for crew injury (*J*).

3. Data

Equations (2) and (4) are estimated utilizing detailed data of individual fishing vessel accidents that were investigated by the U.S. Coast Guard during the 8-year time period 2001-2008 and extracted from the Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) database. The U.S. Coast Guard compiles vessel casualty and pollution statistics and maintains a computer database of detailed records on vessel accident and pollution events in U.S. waters. For the vessel accident data, each observation is a vessel involved in an accident. A long list of variables describes the vessel, time and location of the accident, and other related information (e.g., vessel type and flag). The name and format of the database have changed over the years. Between 1981 and 1991, the vessel casualty database was called CASMAIN. From 1992 to 2001, vessel casualty and pollution records were incorporated into a larger database called Marine Safety Information System (MSIS). Since December 2001, the database has transitioned to the MISLE information system. Three MISLE data tables were used to compile the two data sets (vessel damage and crew injury) for this study. The three data tables include: the Vessel Event Table (MisleVslEvents), the Vessel Table (MisleVessel), and Personal Injury Table (MisleInjury). Only US flagged fishing vessels in the Northeast region were included in the data sets.

Hourly wind speed and sea level pressure recorded from offshore buoys and nearshore weather stations were obtained from NOAA's National Data Buoy Center. Daily maximum wind speeds and daily maximum pressure from each recording station were mapped to different fishing areas by assigning each area to the nearest weather recording station. The spatial feature of accident probability (distance from shore) is the distance from the center of each fishing area to the nearest coast. This was calculated using GIS software and the NMFS digital map of fishing areas.

Variables used in the vessel damage equation estimation, their specific measurements, and descriptive statistics (mean and standard deviation) appear in Table 1. The mean for the dependent variable, damage severity (*D*), is 1.03. Among the accident cases in the data set, 28.5% are classified as vessel "undamaged" ($D = 0$), 40.3% as vessel "damaged" ($D = 1$), and 31.2% as vessel "total constructive loss" or "actual total loss" ($D = 2$). The definition of dependent variable will be discussed further in the next section. The mean statistics for the explanatory variables reveal that the average size and age of a fishing vessel involved in an accident are 74 gross tons and 26.2 years, respectively. 66.2% and 30.7% of the accidents occurred at daytime and in winter, respectively. Most frequent accident types include environmental damage (19.4%), material failure (14.9%), sinking (11.4%), and flooding (11.3%). The average daily maximum wind speed and sea level pressure are 10.6 m/s and 1,018.9 hPa.

Variables used in the crew injury equation estimation, their specific measurements, and descriptive statistics (mean and standard deviation) appear in Table 2. The mean for the dependent variable, crew injury severity (*J*), is 0.127. In the injury data set, 90.8% are classified as "no injury" ($J = 0$), 5.6% as "non-fatal injury" ($J = 1$), and 3.6% as "fatal injury" ($J = 2$). Since both the vessel damage and the crew injury data sets are compiled from MISLE data tables, the mean statistics for the explanatory variables in the crew injury data set are very similar to those in the vessel damage data set. The average size and age of a fishing vessel involved in an accident are 73.5 gross tons and 25.9 years, respectively. 65.8% and 30.3% of the accidents occurred at daytime and in winter, respectively. Most frequent accident types include environmental damage (19.9), material failure (13.6%), and flooding (11.7%), sinking (11.5%). The average daily maximum wind speed and sea level pressure are 10.7 m/s and 1,018.8 hPa.

4. Estimation procedures

As noted above, we develop two sets of models for accident severity, one for vessel damage (*D*) and the other for crew injury (*J*). In both cases, we do not have specific information on accident severity. In the case of vessel damage, the accident vessel is classified as undamaged, damaged, or total loss. Similarly, the crew injury variable has the entries of no injury, non-fatal injury, or fatal injury. As a result, accident severity is a latent variable S^*, i.e.,

$$S^* = \boldsymbol{\beta}'\mathbf{x} + \varepsilon \tag{5}$$

where $S^* = D^*$ or J^*, $\mathbf{x}$ is the set of independent variables, $\boldsymbol{\beta}$ is a vector of parameter coefficients to be estimated, and ε is a normally distributed error term with zero mean and unit variance. Although we do not observe S^*, we do observe the ordinal accident severity variable *S* which is positively related to actual accident severity. As mentioned above, in the vessel damage data set, *D* has three entries, taking on the value of 0, 1, or 2: $D = 0$, if there is no accident damage to the vessel; $D = 1$, if there is accident damage to the vessel; and $D = 2$, if the accident damage to the vessel is classified as a total loss.

Similarly, *J* has three entries in the crew injury data set, taking on the value of 0, 1, or 2: $J = 0$, if there is no injury associated with the vessel accident; $J = 1$, if there are non-fatal injuries in the accident; and $J = 2$, if the accident results in fatal injuries.

In both cases, we have

$$
\begin{aligned}
S &= 0 \quad \text{if} \quad S^* \le 0 \\
S &= 1 \quad \text{if} \quad 0 < S^* \le \mu \\
S &= 2 \quad \text{if} \quad \mu < S^*
\end{aligned}
\tag{6}
$$

where $S = D$ or J, μ is an estimable threshold parameter that distinguishes the accident severity. Given the distribution assumptions on ε, the model defined in (6) is an ordered probit model with choice probabilities (Greene 1997):

$$
\begin{aligned}
\text{Porb}(S = 0) &= 1 - \Phi(\boldsymbol{\beta}'\mathbf{x}) \\
\text{Porb}(S = 1) &= \Phi(\mu - \boldsymbol{\beta}'\mathbf{x}) - \Phi(-\boldsymbol{\beta}'\mathbf{x}) \\
\text{Porb}(S = 2) &= 1 - \Phi(\mu - \boldsymbol{\beta}'\mathbf{x})
\end{aligned}
\tag{7}
$$

with $\mu > 0$ to insure that all probabilities are positive. Φ is the CDF (cumulative distribution function) of the standard normal distribution. The Possible estimation bias from omission of relevant explanatory variables is addressed by including yearly binary variables (see Tables 1 and 2) in the estimations.

5. Estimation results

Vessel Damage Severity

Table 3 reports the results from ordered probit estimation for the D^* in equation (5) using the data set on vessel damage. The table includes results for statistically significant explanatory variables and constant term. The chi-square statistic is large and statistically significant at the 0.01 level. The estimation results suggest that, among accident types, vessel damage severity is greater if a fishing vessel loses its stability, or is involved in a sinking accident. Other types of vessel accident that are associated with greater damage severities include flooding, fire, and material failure. The damage severity is expected to be greater for higher daytime wind speed and less with lower sea level pressure, suggesting that vessel damage severity is significantly affected by weather conditions. Note that under high pressure, weather is typically fair, skies cloudless. But under low pressure, rain, wind and inclimate conditions prevail.

The coefficients of the vessel characteristics variables suggest larger vessels are expected to sustain lower vessel damage, while older vessels are associated with greater vessel damage. Vessel damage severity is expected to be greater if the accident location further away from the shore.

Crew Injury Severity

Table 4 reports the results from ordered probit estimation for the J^* in equation (5) using the data set on crew injury. As in the vessel damage model, the chi-square statistic is large and statistically significant at the 0.01 level. The estimation results suggest that crew injury severity is greater if a fishing vessel's stability is lost, or the vessel is involved in a sinking accident. In contrast, crew injury severity is lower if the vessel accident is limited to equipment failure. The crew injury severity is expected to be lower in the summer than in other seasons (Model I).

To assess directly the effects of vessel damage on crew injury, a second model is estimated using equation (3), and the results are also included in Table 4. According to Model II, there is a statistically significant positive relationship between the crew injury severity and vessel damage severity.

Note that to insure positive probabilities, the threshold parameter μ must be positive. As reported in Tables 3 and 4, the estimate of this parameter in both models are positive and highly significant.

6. Marginal effects

Although the signs of the estimated ordered probit coefficients provide information on whether changes in given explanatory variables increase or lower the accident severity of a fishing vessel, they do not provide information on the extent to which the underlying accident severity probabilities change. For example, what is the impact of changes in the explanatory variables upon the probability of a fishing vessel accident sustaining no vessel damage ($D = 0$) versus the probability of sustaining vessel damage ($D = 1$).

For the ordered probit severity model, the marginal probability effects are:

$$\begin{aligned}
\partial \text{Porb}(S = 0) / \partial \mathbf{x} &= -\phi(\boldsymbol{\beta}'\mathbf{x})\boldsymbol{\beta} \\
\partial \text{Porb}(S = 1) / \partial \mathbf{x} &= [\phi(-\boldsymbol{\beta}'\mathbf{x}) - \phi(\mu - \boldsymbol{\beta}'\mathbf{x})]\boldsymbol{\beta} \\
\partial \text{Porb}(S = 2) / \partial \mathbf{x} &= \phi(\mu - \boldsymbol{\beta}'\mathbf{x})\boldsymbol{\beta}
\end{aligned} \tag{8}$$

where $S = D$ or J, ϕ is the standard normal density function. When $\boldsymbol{\beta}'\mathbf{x}$ is a linear function of x_i (a vector in $\mathbf{x}$), the partial derivative $\partial(\boldsymbol{\beta}'\mathbf{x})/\partial x_i$ is simply β_i , the coefficient of the explanatory variable x_i.

Suppose that an increase in x_i increases fishing vessel accident severity. Then the coefficient of x_i is positive. Thus via equation (8), an increase in x_i increases the probability of the highest accident severity category, $S = 2$, and decreases the probability of the lowest accident severity category, $S = 0$. However, we don't know the effect of x_i on the probability of the accident severity category, $S = 1$. This probability depends upon the extent to which some fishing vessel accidents that are in the lower severity category ($S = 1$) shift into the highest category ($S = 2$), and the extent to which some accidents that are in the lowest category ($S = 0$) shift into higher severity category ($S = 1$). This is seen in equation (8) by the weighted difference in the two standard normal density functions.

Vessel Damage Probability

Table 5 provides estimates of the marginal probabilities for the explanatory variables found in Table 3. If a fishing vessel loses its stability in an accident, it has the highest marginal probability of incurring a total loss (0.668). Other accident types with high marginal probability of a total loss include sinking (0.5313), flooding (0.3109), and fire (0.2985).

As expected, an increase in vessel age by one year is associated with an increase in the probability of total loss by 0.0026. An increase in vessel size by 10 gross tons is associated with a reduction of total loss by 0.0101 (-1.0101/100). If the accident location is one kilometer further offshore, the probability of total lost is higher by 0.0007. For a 1 m/s increase in daytime wind speed, the probability of total lost is higher by 0.009. If the sea level pressure is 10 hPa higher, the probability of total lost is lower by 0.0012 (-0.1228/100).

Crew Injury Probability

Results of crew injury marginal probability estimations for the explanatory variables listed in Table 4 are shown in Table 6. According to Model I, if a fishing vessel loses its stability resulting from an accident, it has the highest marginal probability of incurring fatal injury (0.3191) among all types of accidents. Another accident type with high marginal probability of fatal injury is sinking (0.0494). If the accident occurs in the summer, the probability of fatal injury is lower by 0.015. Results of Model II suggest that if an accident leads to a total loss of the vessel, the probability of fatal injury is higher by 0.082.

7. Conclusion

This study has investigated determinants of the vessel damage and crew injury severities of fishing vessel accidents in the Northeastern United States. Detailed data of individual fishing vessel accidents for the 8-year time period 2001-2008 that were investigated by the U.S. Coast Guard were used to estimate two separate accident severity equations. The equations were estimated utilizing the ordered probit model.

The estimation results suggest that fishing vessel damage severity is positively associated with several types of accidents (e.g., loss of stability and sinking), daytime wind speed, vessel age, and distance to shore. Vessel damage severity is negatively associated with daytime sea level pressure and vessel size. If the accident vessel loses its stability, the probability of a total loss increases by 0.668.

Crew injury severity is positively associated with loss of stability and sinking. Vessel damage severity significantly affects crew injury severity. If a fishing vessel loses its stability resulting from an accident, its marginal probability of incurring fatal injury is higher by 0.3191. The injury severity is negatively related to material failure and summer season. Unlike in the case of vessel damages, the direct effects of weather variables (wind and sea level pressure) on crew injury severity are not statistically significant.

Unseaworthy vessels with inadequate stability have long been recognized as a main reason for the poor safety record in the commercial fishing industry (NRC 1991; USCG 1999). Results of the study indicate that vessel stability concerns should be a long term focus of safety managers and policy makers. While many of the results reported here are consistent with findings from previous studies, two points worth noticing. As noted, fire and explosions were identified as a main cause for crew fatalities on fishing vessels in the 1980s (Jin *et al*. 2001). Similar variables are not statistically significant in the present crew injury severity model, implying improvements in one aspect of vessel safety in recent years, which may be a result of relevant safety regulations governing fire-fighting systems on board fishing vessels (NRC 1991).

Also, an earlier study (Jin and Thunberg 2005) found that fishing vessel accident probability was higher in summer and winter than in spring and fall, and that vessels were most likely to fish in the summer and least likely to fish in the winter, implying that more fatal injuries could occur in the busy fishing season as well. However, results of the present study show that crew injury severity is lower in the summer than other seasons, suggesting that more fatal injuries may occur during off-peak seasons.

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Table 1. Fishing vessel accident damage: variable definitions and descriptive statistics

Variable	Measurement	Mean	Std.Dev.
Dependent Variable			
Damage severity	0 if vessel undamaged (28.5%)	1.0262	0.7725
	1 if vessel damaged (40.3%)		
	2 if vessel total loss (31.2%)		
Explanatory Variable			
Type of accident			
Abandonment	1 if vessel abandoned, 0 otherwise	0.0384	0.1921
Adrift	1 if vessel set adrift, 0 otherwise	0.0075	0.0862
Allision	1 if an allision, 0 otherwise	0.0327	0.1780
Capsize	1 if a capsize, 0 otherwise	0.0187	0.1356
Collision	1 if a collision, 0 otherwise	0.0580	0.2338
Emergency response	1 if vessel requested emergency response, o otherwise	0.0449	0.2072
Environmental damage	1 if vessel caused environmental damage, 0 otherwise	0.1936	0.3953
Explosion	1 if an explosion vessel accident, 0 otherwise	0.0019	0.0432
Fire	1 if a fire vessel accident, 0 otherwise	0.0421	0.2009
Flooding	1 if a flooding vessel accident, 0 otherwise	0.1132	0.3170
Grounding	1 if a grounding vessel accident, 0 otherwise	0.0795	0.2707
Loss of electrical power	1 if vessel lost electrical power, 0 otherwise	0.0084	0.0914
Loss of stability	1 if vessel lost stability, 0 otherwise	0.0084	0.0914
Maneuverability	1 if vessel had a maneuverability problem, 0 otherwise	0.0776	0.2677
Material failure	1 if a material-failure accident, 0 otherwise	0.1487	0.3560
Sinking	1 if a sinking accident, 0 otherwise	0.1141	0.3181
Vessel characteristics			
Vessel gross ton	vessel size in gross tons	74.06	65.18
Vessel age	vessel age in years	26.17	11.93
Type of propulsion			
Diesel engine	1 if vessel is under diesel propulsion, 0 otherwise	0.4967	0.5002
Gasoline engine	1 if vessel is under gasline propulsion, 0 otherwise	0.0094	0.0963
Type of hull construction			
Aluminum hull	1 if aluminum hull construction, 0 otherwise	0.0056	0.0747
Fiberglass hull	1 if fiberglass hull construction, 0 otherwise	0.2301	0.4211
Steel hull	1 if steel hull construction, 0 otherwise	0.3368	0.4728
Wood hull	1 if wood hull construction, 0 otherwise	0.3255	0.4688
Weather condition			
Wind speed	daily maximum wind speed in m/s	10.61	4.05

Sea level pressure	daily maximum sea level pressure in hPa	1,018.86	7.55
Spatial variable			
Distance to shore	km	47.12	45.01
Tine of accident			
Night	1 if nighttime, 0 otherwise	0.3377	0.4731
Daytime	1 if daytime, 0 otherwise	0.6623	0.4731
Season			
Spring	1 if spring, 0 otherwise	0.1833	0.3871
Summer	1 if summer, 0 otherwise	0.2451	0.4303
Fall	1 if fall, 0 otherwise	0.2647	0.4414
Winter	1 if winter, 0 otherwise	0.3068	0.4614
Year			
2001	1 if year 2001, 0 otherwise	0.0430	0.2030
2002	1 if year 2002, 0 otherwise	0.1843	0.3879
2003	1 if year 2003, 0 otherwise	0.1843	0.3879
2004	1 if year 2004, 0 otherwise	0.1759	0.3809
2005	1 if year 2005, 0 otherwise	0.2376	0.4258
2006	1 if year 2006, 0 otherwise	0.1225	0.3281
2007	1 if year 2007, 0 otherwise	0.0262	0.1598
2008	1 if year 2008, 0 otherwise	0.0262	0.1598

Table 2. Fishing vessel accident crew injury: variable definitions and descriptive statistics

Variable	Measurement	Mean	Std.Dev.
Dependent Variable			
Injury severity	0 if no vessel accident injuries (90.8%)	0.1273	0.4271
	1 if non-fatal vessel accident injuries (5.6%)		
	2 if fatal vessel accident injuries (3.6%)		
Explanatory Variable			
Type of accident			
Abandonment	1 if vessel abandoned, 0 otherwise	0.0290	0.1680
Adrift	1 if vessel set adrift, 0 otherwise	0.0103	0.1010
Allision	1 if an allision, 0 otherwise	0.0318	0.1756
Capsize	1 if a capsize, 0 otherwise	0.0187	0.1356
Collision	1 if a collision, 0 otherwise	0.0590	0.2357
Emergency response	1 if vessel requested emergency response, o otherwise	0.0524	0.2230
Environmental damage	1 if vessel caused environmental damage, 0 otherwise	0.1994	0.3998
Explosion	1 if an explosion vessel accident, 0 otherwise	0.0037	0.0611
Fire	1 if a fire vessel accident, 0 otherwise	0.0365	0.1877
Flooding	1 if a flooding vessel accident, 0 otherwise	0.1170	0.3216
Grounding	1 if a grounding vessel accident, 0 otherwise	0.0843	0.2779
Loss of electrical power	1 if vessel lost electrical power, 0 otherwise	0.0084	0.0915
Loss of stability	1 if vessel lost stability, 0 otherwise	0.0103	0.1010
Maneuverability	1 if vessel had a maneuverability problem, 0 otherwise	0.0740	0.2618
Material failure	1 if a material-failure accident, 0 otherwise	0.1358	0.3427
Sinking	1 if a sinking accident, 0 otherwise	0.1152	0.3194
Vessel characteristics			
Vessel gross ton	vessel size in gross tons	73.48	66.25
Vessel age	vessel age in years	25.89	12.30
Type of propulsion			
Diesel engine	1 if vessel is under diesel propulsion, 0 otherwise	0.5037	0.5002
Gasoline engine	1 if vessel is under gasline propulsion, 0 otherwise	0.0084	0.0915
Type of hull construction			
Aluminum hull	1 if aluminum hull construction, 0 otherwise	0.0084	0.0915
Fiberglass hull	1 if fiberglass hull construction, 0 otherwise	0.2088	0.4066

Steel hull	1 if steel hull construction, 0 otherwise	0.3483	0.4767
Wood hull	1 if wood hull construction, 0 otherwise	0.3202	0.4668
Weather condition			
Wind speed	daily maximum wind speed in m/s	10.68	3.93
Sea level pressure	daily maximum sea level pressure in hPa	1,018.75	7.98
Spatial variable			
Distance to shore	km	47.15	45.03
Tine of accident			
Night	1 if nighttime, 0 otherwise	0.3418	0.4745
Daytime	1 if daytime, 0 otherwise	0.6582	0.4745
Season			
Spring	1 if spring, 0 otherwise	0.1845	0.3880
Summer	1 if summer, 0 otherwise	0.2481	0.4321
Fall	1 if fall, 0 otherwise	0.2640	0.4410
Winter	1 if winter, 0 otherwise	0.3034	0.4599
Year			
2001	1 if year 2001, 0 otherwise	0.0440	0.2052
2002	1 if year 2002, 0 otherwise	0.1807	0.3850
2003	1 if year 2003, 0 otherwise	0.1835	0.3873
2004	1 if year 2004, 0 otherwise	0.1770	0.3818
2005	1 if year 2005, 0 otherwise	0.2294	0.4206
2006	1 if year 2006, 0 otherwise	0.1236	0.3293
2007	1 if year 2007, 0 otherwise	0.0309	0.1731
2008	1 if year 2008, 0 otherwise	0.0309	0.1731

Table 3. Fishing vessel accident damage severity equation estimates

Explanatory variable	Coefficient (t-value)
Type of accident	
Fire	0. 7819***
	(3.98)
Flooding	0. 8233***
	(6.35)
Material failure	0. 2946***
	(2.65)
Sinking	1.4491***
	(9.68)
Loss of stability	2.2163***
	(3.88)
Weather condition	
Daytime×Wind speed	0. 0264**
	(2.19)
Daytime×Sea level pressure	-0. 3591**
	(-2.37)
Vessel Characteristics	
Gross ton	- 2.9545***
	(-4.59)
Age	0.0077**
	(2.20)
Spatial variable	
Distance to shore	0.0020**
	(2.06)
Constant	0. 3123**
	(2.28)
Ordered probit parameter, μ	1.2341***
	(21.56)
Number of observations	836
Chi-square statistic	197.589***

*, ** and *** denote significance at 10, 5, 1% significance level, respectively.
Gross ton is in 1,000 ton.
Sea level pressure is in hPa/1000.

Table 4. Fishing vessel crew injury severity equation estimates

Explanatory variable	Model I Coefficient (t-value)	Model II Coefficient (t-value)
Type of accident		
Material failure	-0.5475**	-0.5364**
	(-2.44)	(-2.24)
Sinking	0.5179***	–
	(3.62)	
Loss of stability	1.5239***	1.1461***
	(4.08)	(2.92)
Vessel damage severity		
vessel total loss	–	1.1628***
		(9.61)
Season		
Summer	-0.2585*	-0.2707*
	(-1.91)	(-1.86)
Constant	-1.3305***	-1.7985***
	(-19.12)	(-18.13)
Ordered probit parameter, μ	0.5092***	0.5900***
	(8.12)	(8.18)
Number of observations	1068	1068
Chi-square statistic	41.129***	129.973***

*, ** and *** denote significance at 10, 5, 1% significance level, respectively.

Table 5. Marginal fishing vessel accident damage severity probabilities

Explanatory variable	*D* = 0	*D* = 1	*D* = 2
Type of accident			
Fire	-0.1827	-0.1158	0.2985
Flooding	-0.2000	-0.1110	0.3109
Material failure	-0.0865	-0.0192	0.1057
Sinking	-0.2773	-0.2539	0.5313
Loss of stability	-0.2543	-0.4137	0.6680
Weather condition			
Daytime×Wind speed	-0.0084	-0.0007	0.0090
Daytime×Sea level pressure	0.1138	0.0090	-0.1228
Vessel Characteristics			
Gross ton	0.9363	0.0737	-1.0101
Age	-0.0024	-0.0002	0.0026
Spatial variable			
Distance to shore	-0.0006	-0.0000	0.0007

Table 6. Marginal fishing vessel crew injury severity probabilities

Explanatory variable	$J = 0$		$J = 1$		$J = 2$	
	Model I	Model II	Model I	Model II	Model I	Model II
Type of accident						
Material failure	0.0626	0.0459	-0.0376	-0.0319	-0.0250	-0.0140
Sinking	-0.1017	–	0.0523	–	0.0494	–
Loss of stability	-0.4663	-0.2737	0.1472	0.1369	0.3191	0.1368
Vessel damage severity						
vessel total loss	–	-0.1954	–	0.1135	–	0.0820
Season						
Summer	0.0357	0.0282	-0.0207	-0.0191	-0.0150	-0.0090